VOLUME 79 SEPARATE No. 325

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

NOVEMBER, 1953

BUILDING FOUNDATIONS IN SAN FRANCISCO

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SOIL MECHANICS AND FOUNDATIONS
DIVISION

(Discussion open until March 1, 1954)

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

BUILDING FOUNDATIONS IN SAN FRANCISCO

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The City of San Francisco, unlike many American cities, is built upon hills. In fact, it has more than the traditional seven hills of ancient Rome. Not alone are there hills high above general level but below the surface are deep buried valleys and canyons, and surrounding all are steep submerged slopes leading to the depths of the Bay of San Francisco, the Golden Gate, and the Pacific Ocean. As a result every building site presents a different situation to the foundation engineer, and every foundation a new problem in stability and settlement analyses.

Like Chicago, the down-town district of San Francisco has had a foundation history dating from its earliest days. Beginning with the first influx of population, following the discovery of gold in 1848, there was great demand for water-front property. This soon led to the filling of Yerba Buena Cove, a tidal indentation in the shore line extending from Rincon Hill to Telegraph Hill and lying between Montgomery Street and the present Embarcadero. Later on Mission Bay and low-lying adjacent areas south of Rincon Hill, came into demand for wholesaling and industrial sites and were also filled. All of these filled areas overlie estuary muds, the so-called "soft bay muds", whose depth varies from a few feet to more than 200 feet. Continued and appreciable settlement of buildings and street improvements overlying these soft soils has been the rule and must be considered in foundation design as well as structural stability.

With population growth, the pressure for downtown office space has led to the erection of tall buildings having great load concentrations. This area is located astride the original bay shore line in the transition zone between estuary muds and soft alluvial deposits of sand, sandy clay and clay. The variable subsoils within this area present a serious foundation problem involving both individual buildings and other existing buildings in the vicinity.

Recently, as flatter land has become fully occupied, the steeper hill slopes are in demand for residential and institutional sites. These areas present a problem of stability, arising from the necessity of disturbing the natural slope by cutting and filling, and where proper precautions have not been taken, disastrous slides have resulted. The economic development of these areas to provide safety and stability is one of the difficult current foundation problems.

This paper outlines the geological formations underlying the City of San Francisco, classifies and describes the various types of foundation soils, and presents physical characteristics of the soils with relation to foundation types and designs. Typical settlement data are also given.

In preparing the paper the writer has drawn extensively from the data files of the Charles H. Lee Soil Testing Laboratory as well as those of the Soil Mechanics and Foundations Committee, San Francisco Section, ASCE. The comprehensive published report of the Subsoil Committee, San Francisco

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Section, ASCE, issued in 1932, has also been referred to for the earlier foundation history of the city. For geological background the recent Geologic Guidebook of the San Francisco Bay Counties, published in 1951 by the California State Division of Mines, has been found useful. The cooperation of the staff of the Engineering Geology Branch, U.S. Geological Survey, has been especially valuable.

Geology

The geology of the San Francisco peninsula is so intimately related to that of the whole bay region that it may well be approached from that standpoint. The valley of San Francisco Bay is a structural depression, that is, one which has been produced by crustal deformation of the earth. It has resulted from the tilting of elongated earth blocks along fault zones and with rotational uplife amounting to from 1500 to 2000 feet. These blocks are represented by the Berkeley Hills on the east side of the bay with a steep escarpment facing west and gentler slope to the east; and the San Francisco-Marin block on the west. The elevated escarpment of the latter is represented by the steep western slope facing the Pacific shore line, while its depressed eastern portion lies buried beneath the present bay and against the uplifted western edge of the Berkeley Hills block.

The valley of San Francisco Bay long antedated its flooding with salt water. It developed during the late Pliocene period of active folding and related faulting. Although producing profound changes in local topography these crustal movements occurred slowly, permitting the development of established local drainage systems. The preexisting Sacramento-San Joaquin River system maintained its course across the rising Berkeley Hills block through Suisun Bay and Carquinez Straits, possibly finding initial outlet southerly through Santa Clara Valley to Monterey Bay, but ultimately breaking through the San Francisco-Marin block at Golden Gate.

Tributary to this trunk drainage system were the local streams which drained the valley of San Francisco Bay. These streams cut back rapidly into the freshly created slopes of the adjacent fault blocks, creating new systems of valleys and canyons and depositing their erosional debris on the valley floor as coelescing alluvial cones and valley fill. The elevation of the bedrock outlet of the main trunk channel is probably now represented by the greatest measured depth in the Golden Gate of 63 fathoms (368 ft.). This elevation, carried back by ancient stream bed grades, ultimately reaches the elevations of existing rock bottom stream beds in the valleys and canyons tributary to San Francisco Bay. The ancient stream channels, however, now lie buried, either beneath the mud covering the bottom of the bay, or under the alluvium of the bay-shore coastal fringe and the alluvial deltas filling the drowned valleys. The present stream channels have built up hydraulic gradients controlled by present bay surface elevation rather than bedrock in the Golden Gate. An important aid to an understanding of foundation problems in San Francisco is a knowledge of the ancient topography prior to the flooding of the Bay.

Ancient Drainage Systems

The most important of the ancient drainage systems within the City of San Francisco is Mission Creek draining the area surrounding Mission Dolores. This stream has its headwaters in Hayes Valley lying northwest of the present Civic Center of the city, and Eureka Valley lying to the southeast (Diagram 1).

Historically, streams from these two valleys met near the intersection of Harrison and 11th Streets, flowing thence to an outlet at Mission Bay near Townsend and 7th Streets. Due to the presence of drifting sand deposited in this area by prevailing summer winds the course of Hayes Creek was often blocked causing it to find outlet at various points from 11th and Harrison northeasterly. In historic times the most northerly channel was in the vicinity of 7th and Mission Streets and thence easterly to Mission Bay at 4th and Rosemond Streets.

Bedrock topography indicates that in an earlier geological period the outlet of Mission Creek was to the northeast from the vicinity of Harrison and 6th Streets, roughly following the line of Mission Street between Telegraph and Rincon Hills to Yerba Buena Cove of early San Francisco. From here it turned northwest, flowing between Telegraph Hill and Yerba Buena Island to join the trunk stream from the great Central Valley of California before entering the Canyon of the Golden Gate. Recently developed bedrock topography also indicates that originally the watershed of Mission Creek extended further south to include Noe Valley, which was historically drained by Arroyo Precita, a tributary of Islais Creek. In that period, the Valley of San Francisco Bay had not yet been flooded, and Mission Creek with its larger runoff was able to cut a deep canyon whose narrow bedrock bottom now lies from 200 to 300 feet below the surface of the congested downtown district of the city (Diagram 1).

As salt water backed up into the valley of San Francisco Bay through the Golden Gate, Mission Creek and many other stream-cut canyons were drowned and became estuarial traps where coarser debris from tributary streams was deposited in the form of alluvial deltas and the fines carried beyond to be deposited as marine clays and estuarial mud. In the case of Mission Creek, much of the alluvial debris was wind-blown sand picked up by the stream back of the shore line and redeposited in still water, with silts and clays acquired by the stream in erosion of the weathered bedrock exposed above the level of the sand. In this manner were built up the bedded sequence of sand, silty sand, silty clay and clay encountered in bore holes sunk in the downtown district.

The principal buried stream systems underlying the industrial and warehouse areas of San Francisco are Mission Creek with present outlet at China Basin, but ancient outlet at Yerba Buena Cove; Arroyo Precita and Islais Creek with present outlet at Islais Creek Channel; the drainage area tributary to South Basin, and Visitacion Valley. The upper reaches of all these systems drain extensive residential areas extending back into the hilly districts of the city. Draining the western residential portion of the city are the watersheds tributary to Lake Marced and to Lobos Creek. The Golden Gate Park and Sunset District areas are so extensively buried with sand that the drainage features are not apparent. Directly tributary to Golden Gate in the northern part of the city, including the Presidio, are several small drainage systems having important local significance.

Flooding of San Francisco Bay

It is probable that flooding of the Bay of San Francisco resulted from the rise of the ocean level which occurred with the melting of the great continental ice fields at the end of the last glacial advance (Wisconsin). This occurred some 15,000 to 25,000 years ago and produced a rise in ocean level variously estimated at about 100 meters (330 feet). There may also have been minor crustal movements. With the original mouth of the great river at the west of the Golden Gate, as seems probable, the effect of the 330-feet rise in ocean level was to flood the valley of San Francisco Bay and all of its tributary

stream systems to the present bay level. The valley was thus drowned by salt water invasion and became a trap for most of the sediments discharged into it by tributary streams. These sediments were distributed in accord with grain size as controlled by local currents. The coarser products of shore-terrace erosion accumulated at the base of steeper slopes and rocky headlands, while the finer materials were carried out into deeper water and were progressively deposited as sand and silt beds and, finally, in mud banks. At the heads of estuaries in the drowned valleys typical deltas were formed of the coarser materials while the fines were carried out farther to form deep deposits of soft estuary mud composed of silts and clays flocculated by the chemical action of salt water. However, over most of the bay, the distribution of material was controlled by tidal currents. Here in the quiet shore areas silt was deposited as mud, progressively increasing in size to coarse silt, sand, and, finally, to gravel in the deeper water where the velocity is greatest. The lower portions of valleys and canyons, forming the original topography of San Francisco before flooding, have thus become filled with alluvial material which, in some locations, extends to depths exceeding 250 feet. Inshore, these deposits are sandy, but in the lower parts of the city and along the waterfront there are extended bodies of deep soft mud which constitute a major foundation problem in stability. Even where interbedded with sand there exists the possibility of excessive settlement.

Windblown Sand

Following the rise of ocean level there has been a formation of beaches, spits and bars of sand along the ocean shore. These have been especially prolific on the San Francisco Peninsula south of Golden Gate where a counter eddy in main southbound oceanic currents picks up sand from cliffed headlands in San Mateo county and carries it north, depositing it along the ocean beach from Golden Gate Park south. There the sand has formed bars across the mouths of drowned valleys, creating inland lagoons, such as Lake Merced, and, in some cases, completely filling the valleys to form swampy areas back of the beach ridges. The continuous westerly winds, prevalent along the coast in this locality, have carried enormous quantities of sand inland, created waves and trains of sand dunes and buried the original topography over much of the ocean frontage of the city comprising the Sunset District.

Much sand has also been carried through wind gaps in the hills and over the tops of the ridges and deposited over the lower portions of the northeastern and eastern sections of the city. The principal wind gap is from Golden Gate Park through the Park Panhandle. This is supplemented by the low saddle in the ridge of hills between Geary and California Streets, at the former site of Laurel Hill Cemetery. Sand carried through these gaps has buried Hayes Valley, the Civic Center area, the downtown area to the waterfront, Eureka Valley and the North Potrero District. Further south is the wind gap at the junction of Mission and Dolores Streets through which sand has been spread over Noe Valley.

In the early days a group of large sand dunes occupied the area between Montgomery and Stockton Streets This material has all been removed and used for filling tidal marsh and waterfront property. Wind-blown sand had, in several areas, drifted across long-established drainage channels, causing winter storm waters to spread. Rank growing vegetation in ponds and swamps have created local beds of peat and organic matter which later became buried with sand and thus became potential settlement hazards. One of the largest of these areas is in the vicinity of Civic Center and extending north and east,

forming what was known in the early days as the Mission Swamp. Among early civic enterprises was the construction of a plank road along Mission Street and a log crib bridge across the swamp. Piles were tried initially to support the bridge but were abandoned when a forty-foot pile disappeared at the first blow of the hammer. The instability of this area was demonstrated at the time of the 1906 earthquake.

Subsurface Records

The complex occurrence of subsurface materials in San Francisco has led to the assembling and publishing of well drillers logs and the preservation of foundation test boring records. The first publication of this type was issued in 1913 by the late M. M. O'Shaughnessy, M. ASCE, City Engineer of San Francisco, entitled "Report on the Underground Water Supply of San Francisco County," and containing logs of more than 300 wells. In 1932 the "Subsidence Report of the Subsoil Committee," San Francisco Section, ASCE, was published, containing many records of wells and foundation test borings. More recently The Institute of Transportation and Traffic Engineering, University of California, in cooperation with the local office of the U. S. Geological Survey, Engineering Geology Branch, published "Selected Logs of Borings," which contains data for 437 borings, many of them made since 1932. (Information Circular No. 11, Dec. 1950). These compilations are very useful to the foundation engineer practicing in San Francisco. In addition to the published data, the U. S. Geological Survey, Engineering Geology Branch, maintains a file available for public inspection of over 2000 logs of borings made in the City of San Francisco. The records are being collected by a field party in connection with the preparation of geological maps and a report soon to be published on the geology of San Francisco. This report will be a very valuable addition to the foundation literature of San Francisco.

Foundation Materials

Foundation materials underlying the City of San Francisco are quite varied in character, as might be concluded from the preceding review of the complex local geological history. The principal types are listed and described as follows:

Bedrock

This may be defined as rock in place. It may include fractured, partially weathered and softened rock but it does not include rock in which weathering and chemical decomposition has progressed far enough to produce general softening or to form silt or clay.

The principal types of bedrock in San Francisco include (1) arkosic sandstones and shales of the Franciscan series, (2) intrusive and submarine flow basalts (pillow basalt), (3) radiolarian cherts which are closely related to the basalt, and (4) intrusive periodotite which has been largely serpentinized. The Franciscan rocks are extensively folded and faulted with beds standing at high angles. The massively bedded Franciscan sandstones form the basic rock material of the area. The rock is so broken, permeated and enveloped by intrusive and extrusive igneous rock, however, that it is difficult to predict what will be encountered in a boring at any given point.

Franciscan Sandstones and Shales. These are sedimentary, being derived from a landmass of crystalline rocks now submerged, which lay west of the

present coast line. Because of severe climatic conditions, mechanical rather than chemical decomposition of the crystalline rock occurred, so that feldspars and other easily decomposed minerals eroded from the land mass were deposited beneath the sea in a fresh condition where they were consolidated, sometimes with organic material. The shales were similarly formed, being composed by finer detritus. They are dark in color and decompose into smooth soft clay. Unweathered sandstone rock is bluish-gray in color with black or dark brown spots of organic matter. It is hard and firm with granular texture. At depth, as encountered in tunneling operations, the rock may be softened by deep weathering adjacent to fractured or broken zones, but retains its color. Near the surface, weathered rock is tawny yellow in color and broken into softened angular fragments embedded in more or less clay. The weathering process consists of chemical decomposition of the feldspars to form a soft yellow clay more or less sandy, depending upon the degree of decomposition. If the volumetric percentage of clay in weathered rock exceeds the voids between angular fragments of the rock, the mass, especially if softened by water, acts more or less as a clay. Franciscan sandstone forms a good foundation material if unweathered and not too badly fractured. When weathered or extensively fractured it should be thoroughly investigated throughout the foundation area and, if economically feasible, all footings or piers carried down to sound rock. If firm rock is sought the first showing of rock should be prospected, for at least 10 feet, to determine whether there are pockets of soft weathered intrusive rock below. In open cuts Franciscan sandstone stands at slopes of from 1-1/2:1 to 2:1, depending upon the amount of included shale and the degree of weathering.

Basalt. Accompanying the formation of Franciscan sandstone and shale, and after deposition of from 5,000 to 10,000 feet of arkosic sediments in shallow water upon the ocean floor, widespread submarine volcanism commenced with sea-floor eruptions of lavas, chiefly basaltic. The lava overturned in flowing to form the so-called "pillow basalts" whose characteristic form is often seen at exposures in road cuts or sea cliffs. Associated with the basalt is volcanic ash derived from submarine explosions and intermixed with normal sedimentary material. Basaltic flows are often interbedded with sandstone and shales, as well as being intrusive. Franciscan basalt is dark green and greenish-black in color when fresh and red dark-brown in color when altered. It is generally deeply weathered and partially decomposed, breaking down rapidly when exposed. The end product of decomposition is a pale red, putty-like clay of montmorillonite type. Basalt is a poor foundation rock because of its being softened by weather and the possibility of there being pockets of soft clay where fissured or fractured zones permit entry of water. In open cuts it will not stand for long periods at slopes steeper than 1-1/2:1. In tunneling operations the rock spalls rapidly if not covered, and soft clay pockets may be encountered.

Chert. Interbedded and associated with basalt in the Franciscan series are the radiolarian cherts. These are silicious, chemically deposited sediments whose silica is thought to have been derived largely from the volcanic materials although the microscopic shells of silica-secreting radiolaria are present. Both iron and manganese occur in the cherts. The prevailing color of chert is red but may be modified by the state of oxidation of iron or manganese to white, pale pink, yellow, brown, green or black. The cherts are regularly bedded, the individual layers averaging 2 to 3 inches in thickness. Shale partings from paper thickness up to 1 inch separates each chert layer. Although originally colloidal the cherts have become crystalline through metamorphic processes. They are hard and brittle, readily breaking into granular

debris of 1/4 inch maximum size. Cherts make good foundation material if unbroken, and stand well in cuts at from 1/4 to 1/2:1, being held together by the shale partings. Over head in tunneling operations they are treacherous and if permitted to stand unsupported may ravel, with bad caving.

Serpentine. The Franciscan series of rocks is extensively intruded by periodotite and dunite, rocks which are crystalline and hard, composed of varying proportions of the basic silicated, olivine and pyroxene. These rocks, during the process of intrusion, have produced shearing zones along the contact faces which extend both into the intruding masses and into the original rock. Subsequent to intruding, the peridotites have been altered almost completely by hydrothermal action to form the softer and weaker rock known as serpentine. This change was accompanied by swelling, with resultant high pressures which have produced extensive internal shearing and formation of numerous shiny, slippery surfaces throughout the rock. Chemical by-products have also been produced such as soapstone and chrysotile asbestos which permeate the mass. Serpentine occurs extensively in the San Francisco Peninsula and is of three forms: massive unsheared rock, dark green to black in color; partially sheared rock with rounded nodules of hard green rock in a matrix of sheared rock of greenish-gray color with waxy lustre; and completely sheared rock. Serpentine masses are usually badly cracked, with little or no soil cover, so that water enters easily. Rock masses weakened by shearing, internally lubricated by slippery alteration products, are unstable when wet and have a tendency to slide. Such rock at the base of the bluffs along the south side of Golden Gate is progressively undermining the cliffs and causing slides. Serpentine, which has weathered and decomposed in place, forms a soft slick clay which, in the San Francisco area, is of montmorillonite type.

Continued alteration of serpentine or soapstone by water with carbonate in solution produces a hard silica-carbonate rock made up of chalcedony, opal, quartz and magnesium carbonates. This rock weathers to a rust-brown or light-tan porous rock which often stands out in bold relief in cliffs, knolls, or reefs. These hard masses are surrounded and interspersed with punky soft material which occurs in irregular pockets, forming a plastic putty-like clay when moist. This material may be a source of serious difficulty in foundation areas.

Massive unbroken serpentine forms a good foundation material but sheared serpentine should be avoided. The presence of silica carbonate rock is an indication of soft clay pockets. The allowable slope of cuts in sheared serpentine depends upon the condition of the rock.

Clay

This is a general term applying to beds, lenses or pockets composed of true clay particles of colloidal size and scale-like texture, or to mixtures of clay with silt or minor amount of sand. It is characteristically plastic and cohesive when wet, hard and brittle when dry, subject to shrinkage and expansion with moisture change, and slowly compressible when loaded. Clays in the San Francisco area are of residual, alluvial, or marine origin.

Residual Clays

These are the product of chemical decomposition of the rock upon which they lie, normally as a subsoil layer but also occupying fractures, seams, fissures or pockets in the rock. Chemical decomposition may be caused by weathering accelerated by fracturing, or fissuring of the rock, or by

hydrothermal action from below. Residual clays, derived from Franciscan sandstone and shale, derive their character from the basic feldspar particles and are largely of the morillonite type. They tend to greater sandiness than other types of residual clays but have the same inherent weaknesses when wet.

Clay derived from basaltic rock is of the montmorillonite type with fine, smooth texture and high compressibility. These clays are very weak when wet and have the qualities of skid grease. If lying upon a slope they will act as a plane of sliding for a superimposed structure or fill.

Clays derived from serpentine are slippery and talc-like and have great weakness when wet. A broken mass of serpentine is a potential slide hazard especially with clay in the seams. A clay subsoil upon serpentine is also treacherous. Soft clay pockets, associated with silica-carbonate rock masses, are especially bad.

Residual clays in the San Francisco area are not acceptable foundation materials when located upon sloping bedrock or in bedrock seams or pockets and should be thoroughly investigated before acceptance even under more favorable conditions.

Marine Clays. Included under this heading are the deeper fine-textured dark blue or green clays deposited from salt or brackish water in coves and estuaries of San Francisco Bay during the earliest geological stage of submergence. These clays were usually deposited upon the original presubmergence topography and have become consolidated either by exposure and desiccation or by long-continued loading. Such clays may be acceptable for foundations if occurring in extensive beds but should be checked for strength and possible further settlement due to consolidation under load. These clays do not include estuary mud (soft bay mud) which is discussed later.

Alluvial Clays. These are derived from residual clays and from rocks softened by weathering or by hydrothermal action, subsequently eroded and transported by flowing storm waters, and deposited in areas of overflow or in ponded or quiet fresh water. They are yellow or brownish yellow in color and usually contain more or less silt and sand.

The greatest accumulations of alluvial clay, usually interbedded with clayey or silty sand and sand, occur in the drowned lateral valleys of the geologically old Valley of San Francisco Bay. These materials were built up as deltas at the heads of estuaries with characteristic top set and foreset beds. These deltas merge into dark-colored estuary mud deposits where the suspended fines carried beyond the delta area into the lower estuarial waters came in contact with salt water. Their value as foundation material depends upon shearing strength and consolidation characteristics and is usually good for lighter loads, subject to possibility of excessive or unequal settlement. The possible presence of local lenses of organic matter or of soft pure clay should be investigated.

Estuary Muds. The dark-colored estuary muds, or "soft bay muds" as often reported by drillers, are composed of particles of silt and clay of colloidal size mingled with organic matter and often marine shell fragments. This material is the product of the flocculation which occurs when silt and clay in fresh water suspension come in contact with salt water. The resulting deposits are light in weight, soft, and often of a jelly-like consistency. Although somewhat cohesive and resistant to jetting they have little supporting capacity and are easily penetrated by piles. Accumulations of estuary mud occur to great depth all along the San Francisco water front and extending inland into the ancient geological estuaries created as the ocean water rose and formed the present bay.

Extensive areas of estuary mud, originally submerged in coves or exposed on tidal flats, have been filled during the history of the city and now underlie paved streets and built-up lots. The extent of such areas is shown upon Diagram 1. Along the waterfront, beyond street and property lines, estuary mud extends into the bay, underlying the seawall and pier areas and forming a blanket over the whole bay bottom except in areas of active tidal current. Estuary mud has very poor supporting capacity and foundations in such areas must be supported on piles.

Due to variations in the rate of rise of the ocean waters or to the fluctuation of land elevation during geological periods, the deposition of estuary mud has been locally interrupted so that beds of more resistant alluvial materials occur interbedded with mud. It has been found necessary at large building sites in estuary mud areas to extend foundation explorations through such firmer deposits to determine whether they overlie deeper soft muds which might be the cause of excessive settlement. Occasionally a sandbed of substantial thickness and extent will be found within a mud deposit which offers support for piles, but, on the other hand, small floating areas of firmly cemented sandy clay have been encountered at some points, necessitating jetting operations before piles could be driven to a dependable firm bearing.

Swamp deposits. The effect of shifting windblown sands in an area traversed by stream flow or intermittent storm runoff is to build up and maintain a shallow water table or to create ponding, thus producing swampy conditions. This results in the active growth of rank vegetation, with accumulations of soft organic matter more or less mixed with silt and clay forming beds of peat or muck. Beds of such material, subsequently buried by inorganic alluvium or windblown sand, remain saturated and may act as liquids under pressure, or as highly compressible strata. Such conditions existed in the early days of San Francisco along valley troughs and in the lower portions of stream valleys throughout the sands areas of the city. They were especially prevalent in the lower portion of Hayes and Eureka Valleys in the area formerly known as the Mission Swamp which extended from the present Civic Center east and south. Soft beds of black organic matter occur at various levels in this area and may be a source of instability as well as excessive settlement. Much earthquake damage occurred in this area in 1906. Local areas of buried swamp deposits also occur in other parts of the city, such as the Marina.

Fill. Large areas back of the present water front formerly lay in submerged coves and estuaries, or tidal flats and swamp land, which at sometime during the history of the city have been filled to form "made ground" for building sites. Much of the fill material is sand from the adjacent sand dune areas and rock excavation waste, but mingled with it is often miscellaneous junk and rubbish consisting of waste from building demolition, industrial plants and garbage. In the cove areas are great numbers of old wooden piles driven during the early history of the city. On lower ground and in swampy areas such fill material has partially sunk into the underlying soft mud and forms a cohesive but more or less flexible crust as lubricated by infiltrated mud and water. Such ground is very unstable. Further back from the waterfront where deposited upon alluvium, fill material has not experienced saturation with its resultant consolidation and hence is often very porous. All such filled ground and the black loam soil areas formerly valuable as truck gardens are poorly consolidated and require thorough investigation before preparing foundation plans.

Sand

Sand in the San Francisco area is of two types; (1) the windblown sand, predominantly silicious, derived from the Ocean beaches, subangular to rounded in shape, of uniform texture and of medium grain size (0.1 to 0.4 mm); and (2) alluvial sand derived by erosion from Franciscan sandstone bedrock and predominately feldspathic. Pure windblown sand lies upon the surface and to varying depths from 5 to 10 feet up to 30 or 40 feet, depending upon the original topography, local wind currents and eddies, and the action of flowing streams. Alluvial sands interbedded with silty sand, sandy silt and clay and silty clay lie at greater depths which, in the lower portions of the larger drowned valleys, may exceed 300 feet. The extent of windblown sand in the city is great.

When deposited in the vicinity of stream channels, wind-blown sand is often eroded by flood water runoff and redeposited in alluvial beds, sometimes free from admixture, but frequently mingled with silt and clay derived from bedrock erosion and sometimes organic matter. This process is the origin of alluvial, clean silicious sand interbedded with layers of sticky, silty, and clayey sand or muck, such as is encountered in borings. Occasionally, beds of silty sand are encountered in which the granular particles are of feldspar. Such particles may be encased in a clay matrix which is the product of their own decomposition. These particles are soft and such sands, when tested in shear, give much lower angles of internal friction than do the harder silicious sands.

Bodies of sand are satisfactory for foundations if confined, confinement being especially important on sloping ground. Dirty or silty sand should be identified as to mineral composition of the granular particles. Thorough tests should also be made for angle of internal friction, cohesion, void ratio, and unit weight. Silicious sands have a high angle of internal friction but feldspathic sands are soft and weak in internal friction. Alluvial sand deposits are often poorly consolidated in their natural state and experience reduction of volume with consolidation and rapid settlement under load. Wind-blown sands may also experience consolidation. Compaction of subgrade for light buildings can best be secured by rolling with heavy rubber-tired equipment.

Gravel

Gravel reported in drilling logs may be either residual or alluvial. Residual gravel consists of broken rock fragments or nodules of more resistant rock within the zone of rock weathering and embedded in a matrix of softened rock or residual clay. Where the volume of the soft matrix exceeds the voids between rock fragments, the matrix may change volume under load by consolidation or plastic flow with resulting settlement. This can be avoided by carrying foundation footings either to hard rock or to broken rock in which the soft matrix does not exceed the voids.

Alluvial gravels are of rare occurrence in San Francisco because of the absence of weather resistant rock. It is confined to the vicinity of larger stream channels and to the uppper portions of ancient drowned valleys back of the ancient bay shore line.

Physical Characteristics of Foundation Materials

The more important physical characteristics of soils from the standpoint of foundation design are unit weight, moisture content, void ratio, consolidation, and shearing strength including its components of cohesion at zero load

and angle of internal friction. Supplementary tests are sometimes made for true specific gravity, Atterberg limits, mechanical analysis by sieve and hydrometer method, and unconfined compressive strength. Values for the more important physical characteristics of foundation materials in the San Francisco area have been compiled from the records of the Charles H. Lee Soil Testing Laboratory and are submitted on the accompanying Table 1. Tests were made upon undisturbed samples taken with a thin-walled Shelby sampling spoon 3 inches in outside diameter by 18 inches in length, with thickness and area ratio of approximately 0.15. Sampler tubes were dipped in wax before use and were sealed with wax immediately after recovery. Laboratory samples were cut as needed from the progressively extruded field samples.

General Test Data

Sample materials, listed on Table 1, have been broadly classified as wind-blown, alluvial, and residual. The textural classification is the result of field inspection, checked by settling tests made in the laboratory. The U.S. Bureau of Soils grain-size limits were used for sand, silt, and clay. Materials have been arranged on Table 1 by texture from coarse to fine. Although no consistent change in unit weight or void ratio with texture is indicated on Table 1, there is a marked change in the angle of internal friction. This varies progressively from 36^0 or more for clean sand to $5^0 \pm$ for estuary mud. There is also a corresponding increase in cohesion with decreasing size in the alluvial materials. The strongest materials in cohesion are usually the sandy silt and clays and the weakest the esturial muds and moist residual silts and clays.

Typical assemblies of test data for undisturbed samples taken from a group of test borings on the San Francisco waterfront are shown graphically on Diagrams 2 and 3. Nine borings were carried to rock at depths of from 140 to 160 feet, penetrating soft estuary mud for the first 60 feet, then a bed of medium to fine sand averaging 17 feet in thickness, and, finally, a bed of medium stilff, slightly clayey silt with organic inclusions, having thickness of from 50 to 75 feet. This site was specially investigated because of the presence of a substantial stratum of sand in soft esturarial mud. The graph of effective natural surcharge load (Diagram 2) was prepared from unit weight tests of the various subsurface materials with correction for submergence below the water table. Values from this graph, increased by superimposed structural dead and live loads when entered upon the appropriate shearing diagram (Mohrs envelope), provide values for the shearing resistance as required for stability and other analyses (see Diagram 4).

The comparison throughout the soil profile of unconfined compressive strength tests with shearing strength at normal surcharge load combined with void ratio, as presented on Diagram 3, is of special interest. The great spread in the plotted points for compressive strength appears to be caused by the greater variation of conditions in the plane of the angle of failure, which varied from 57^0 to 45^0 with the horizontal, as compared with conditions in the plane of failure in shearing which was horizontal and lay with the natural bedding planes. Maximum stress values computed from shear test data, when compared with maximum stress from unconfined compression tests, indicate lower values, the average for 20 tests being 73%. This is also thought to result from the laminated condition of the clayey silt whose horizontal parting planes are weaker in shear than the diagonal planes along which failure occurs in unconfined compression. These horizontal planes

TABLE 1

PHYSICAL PROPERTIES OF TYPICAL FOUNDATION MATERIALS
SAN FRANCISCO, CALIFORNIA

MAP LOCATION NO. DIAG. 1	FEET IN DEPTH	STREET LOCATION	UNIT WEIGHT PCF.	MOISTURE CONTENT % DRY WT.	VOID RATIO e	ANGLE INTERNAL FRICTION ø (a)	COHESION AT ZERO LOAD PSF. C (a)
		DUNE SAND (Wind-blown, medium to fine size)					
1	5	Divisadero			•	35° 35'	0
1	50	and Sutter				36° 30'	0
2	26	Turk & Franklin	100	4	0.68	32° 30'	0
		ALLUVIAL SAND (Medium to fine)					
3	Avg. 8 65 - 72	Islais Cr. Basin	109	18	0.53	51°	674
4	35	19th & Folsom	105	20	0.59	51°	950
		SILTY SAND (Alluvial)					
4	15	19th & Folsom	102	18	0.63	43° 30'	880
		CLAYEY SAND (Alluvial)					
5	12-1/2	26th & Harrison	105	19	0.59	24°	1350
5	24-1/2	" "	104	30	0.61	47° 30'	290
6	40	Main & Folsom	105	22	0.59	34° 30'	850
5	7	26th & Harrison	105	14	0.59	55°	370
		SANDY SILT (Alluvial)					
4	20	19th & Folsom	100.5	18	0.66	42°	650
4	11	" "	106	19	0.57	20°	2710
4	25	" "	99.5	24	0.63	16°	1750
4	40	" "	83.8	33	0.99	18°	2180
4	45	" "	109.1	17	0.52	29°	950
5	8	26th & Harrison	88	29	0.90	14°	610
		SANDY CLAY (Alluvial)					
2	26	Turk & Franklin	110	19	0.53	0	1440
2	27	" "	110	18	0.53	13°	1680
7	53	Divisadero & Post	113.8	18	0.49	35° 45'	260
		SANDY CLAY (Residual)					
3	150 (d)	Islais Cr. Basin	109	19	0.53	24° 30'	2300
		SILT (Residual)					
8	(e)	Alemany Blvd. near end Ellsworth				0 (b) 23° (c)	835 1007
		CLAY (Residual)					
8	(f)	Alemany Blvd. near end Ellsworth				13° (b) 13° (c)	830 2300
-	(g)	Camden Ave., San Mateo, Calif.	118	25	0.42	5°	820

TABLE 1 - Cont.

MAP LOCATION NO. DIAG. 1	FEET IN DEPTH	STREET LOCATION	UNIT WEIGHT PCF.	MOISTURE CONTENT % DRY WT.	VOID RATIO e	ANGLE INTERNAL FRICTION ø (a)	COHESION AT ZERO LOAD PSF. C (a)
		ESTUARY MUD (Alluvial)					
3	Avg. 6 10 - 25	Islais Creek B.	58	62	1.88	4°	142
3	Avg. 4 30	" " "	62	61	1.67	6°	180
3	Avg. 7 35 - 60	" " "	68	59	1.45	5° 30'	512
3	Avg. 25 76 - 138	" " "	71	52	1.36	7° 45'	1018

(a) Quick shear tests madewith U. S. Bureau of Public Roads type of shear machine. Test samples 1-15/16 ins. diameter, 0.72 ins. high, trimmed from 2-7/8 ins. diameter field samples. Shearing load applied at rate of 0.02 ins. per min. Three to five runs were made on each sample at differing surcharge loads to determine values for ø and C.

(b) Plastic no-creep condition (beginning of plastic flow).

(c) Ultimate plastic failure.

(d) Hard green clay (altered Franciscan sandstone).

(e) Brown silt (altered sheared serpentine).

(f) Brown clay (altered silica carbonate).

(g) Brown clay (altered basaltic lava rock).

were plainly visible in most of the test samples when removed from the sample cutter, especially those taken at greater depths. For seasonal water deposits it is concluded that shear test data are more reliable for design purposes than unconfined compression tests. For soft cohesive materials deposited continuously from water or formed by weathering of massive rock unconfined compression tests may give more uniform results. In any case, they are useful for screening a large number of samples for a more intensive testing.

Consolidation Test Data

The physical conditions of subsurface materials are so variable with respect to degree of consolidation that test results have little meaning beyond the particular site to which they apply. In general, it may be said that the most compressible materials, in order of degree, are swamp deposits, soft bay mud, blue marine clay, yellow silty clays and yellow sandy clays. Methods of analysis of consolidation test data may be of interest. Those in use by the writer depart from the well-known Terzaghi method in order to attain greater accuracy in estimates of expected settlement. As illustration, the results of a recent test made on blue marine clay at a depth of 110 feet, at the intersection of Sutter and Montgomery Streets, San Francisco, is presented. (See Diagrams 5 and 6.) Consolidation characteristic graphs (Diagram 5) are plotted in terms of log pressure, and include the loading curves in terms of

void ratio, the coefficient of consolidation, and the primary compression ratio, the latter as determined by the square root of time fitting method. (See Diagram 6.) The change in void ratio during compression is considered to be composed of three elements - precompression, and primary and secondary consolidation - as has been established by the work of Donald W. Taylor, A.M., ASCE, Massachusetts Institute of Technology, in his "Fundamentals of Soil Mechanics," pp. 208-247, 1948.

The precompression of the sample occurs almost instantly when load is applied. It is that portion of the "change in void ratio versus $\sqrt{\text{time}}$" curve which lies above the intersection of an extension of the straight portion of the curve with the zero time axis. It is considered to represent compression of gases within the soil fluid and for which no lag due to drainage or plastic flow occurs. This is indicated by the observed decreases of precompression with depth.

Primary Consolidation is that which occurs during the period when the resistance of the water to drainage, as it is migrating under the induced pressure, carries the greater portion of the load. It is to this portion of the total compression that the classical Terzaghi method of time analysis applies, such method being based upon the assumption that the resistance to flow of the pure fluid, under the induced hydrostatic load, produces the entire time lag in the consolidation.

Secondary, or plastic, consolidation is that which occurs when the resistance of the material to plastic deformation, by rearrangement of granular structure (not plastic flow), carries the greater portion of the load. Plastic readjustment of granular structure takes place during the entire compression period, but is considered to be dominant only in the latter portion of the $\sqrt{\text{time}}$ curve. It produces the inclined tangent instead of a flat line in the latter portion of the load versus void ratio curve and gives rise to a small, fairly uniform, settlement for many decades. In all portions of the consolidation process plastic resistance slows the actual consolidation and causes predicted settlements to be greater than those which actually occur.

Consolidation in a pure clay, free from gases, is essentially all primary, while that in pure granular materials is essentially all secondary. Consolidation in materials consisting of mixtures of sand, silt, and clay is predominantly either primary or secondary, depending upon the degree of permeability of the material. The following tabulations give relative percentages of the total, as found for various types of material.

The foregoing values illustrate the large percentage of total consolidation which occurs as precompression with increased loading upon sand (100%), and upon beds with included gases (20 to 60%). They also indicate the relative proportions of primary and secondary consolidation in various types of cohesive materials. Primary consolidation in cohesive materials varies from 42 to 70% of the total and secondary from 23 to 48%. The conventional Terzaghi method of computing settlement assumes that the expulsion of water represents the whole of the consolidation process instead of only the primary phase. The Taylor method, on the other hand, permits segregation of the various processes and provides a more accurate forecasting of the time schedule for settlement.

It is to be noted that the percentages given in Tables 2 and 3 are test values where drainage capacity is adequate. In the case of deep compressible materials, such as blue marine clay lying below yellow alluvial clay beds, the percentage of primary consolidation may be controlled by natural drainage and if this is inadequate incipient hydraulic conditions may develop, resulting in plastic flow rather than plastic granular readjustment.

TABLE 2

CONSOLIDATION AS PERCENT OF TOTAL FOR ESTUARIAL MUD SAN FRANCISCO WATERFRONT AT MOUTH OF ISLAIS CREEK

(Location No. 8, Diagram 1)

MATERIAL AND THICKNESS OF ZONE	SAMPLE NO.	CONSOLIDATION-PERCENT OF TOTAL		
		Precompression	Primary Consolidation	Secondary Consolidation
Highly organic silt preconsolidated	2-90'	17	72	11
by dessication - 15 ft. (a)	7-91'	22	53	25
Greasy-textured clayey silt moderately organic - 15 ft.	9-101'	8	44	48
Stiff inorganic clayey silt - 15	1-120'	4	58	38
ft.	2-120'	3	60	37
Highly organic silt - 10 ft.	4-132'	2	65	33
	5-133'	2	69	29
	4-132'	2	66	32
	5-133'	2	70	28

(a) Underlying 16 to 20 ft. of medium to fine sand which, in turn, underlies 65 ft. of soft bay mud.

TABLE 3

CONSOLIDATION AS PERCENT OF TOTAL FOR ALLUVIAL AND MARINE BURIED DEPOSITS

(Location Nos. 4 and 9, Diagram 1)

MATERIAL AND THICKNESS OF ZONE	SAMPLE NO.	CONSOLIDATION-PERCENT OF TOTAL		
		Precompression	Primary Consolidation	Secondary Consolidation
ALLUVIAL DEPOSITS				
Silty fine sand - 20 to 38 ft.	6-15'	100	0	0
Sandy silt - 20 to 30 ft.	1-25'	56	42	2
Wind-blown sand - 8 ft.	1-35'	100	0	0
Tough sandy fistulated silt - 7ft.	1-40'	60	17	23
MARINE DEPOSITS				
Sandy fine silt with shell and organic matter - 10 ft.	6-40'	20	44	36
Blue marine clay.	1-110'	9	56	35

Settlement Records

Those portions of the city in which fill has been placed over soft estuary mud or swamp deposits have from early times experienced appreciable settlement. In the former swamp areas the rate of settlement has varied considerably from point to point, as influenced by greater depth of accumulation of soft materials in the vicinity of old stream channels. In the filled estuary and cove areas of the bay shore the rate of settlement has been more uniform. The settlement has been excessive in certain areas and it has necessitated the making of extensive repairs to public improvements and utilities at more or less regular intervals. The most extensive of such areas is along lower Market Street from Sansome to the Embarcadero where street paving has had to be raised to official grade several times during the history of the city. Local areas of soft ground occur in the former Mission Swamp south of Market Street and other wet areas.

Street Intersections

Several years ago the Soil Mechanics and Foundations Committee, San Francisco Section, ASCE, working in cooperation with City Engineer Ralph Wadsworth, M. ASCE, was instrumental in having a compilation made of all available data in his office of elevation of paving and curbs at street intersections in the recognized areas of settlement. The compiled records in the form of 8-1/2 x 11-inch graphs at each of 157 street intersections extend over a period of about 25 years from 1920 to 1943. Average annual rates of settlement in feet computed from the records have been tabulated for portions of typical streets in the filled areas of the city, as shown on Table 4 below:

TABLE 4

**AVERAGE ANNUAL RATE OF SETTLEMENT 1925 to 1943
FOR TYPICAL STREETS IN FILLED AREAS OF SAN FRANCISCO**

CITY ENGINEER'S INDEX MAP NO.	INTERSECTING STREETS	HISTORIC LOCATION OF UNDERLYING SOFT MATERIALS	AVERAGE ANNUAL RATE OF SUBSIDENCE - ft./yr
	EMBARCADERO		
157	Broadway	Yerba Buena Cove	.028
139	Jackson	" "	.052
143	Washington	" "	.058
136	Clay	" "	.053
129	Sacramento	" "	.050
113	So. Market	" "	.042
106	Mission	" "	.032
99	Howard	" "	.036
93	Folsom	" "	.050
Avg.			.044
88	Harrison	" "	.005
	MARKET STREET - NORTH SIDE		
129	Sacramento	Yerba Buena Cove	.050
123	California	" "	.029
118	Pine and Davis	" "	.040
117	Pine and Front	" "	.045
114	Bush and Battery-prior 1930	" "	.020
	1930-1940	" "	.067
Avg.			.041

TABLE 4 - Cont.

AVERAGE ANNUAL RATE OF SETTLEMENT 1925 to 1943 FOR TYPICAL STREETS IN FILLED AREAS OF SAN FRANCISCO

CITY ENGINEER'S INDEX MAP NO.	INTERSECTING STREETS	HISTORIC LOCATION OF UNDERLYING SOFT MATERIALS	AVERAGE ANNUAL RATE OF SUBSIDENCE - ft./yr.
	MARKET STREET - SOUTH SIDE		
113	Embarcadero	Yerba Buena Cove	.042
112	Stewart	" "	.037
111	Spear	" "	.020
110	Main	" "	.024
109	Beale (1938 to 1943 only)	" "	.017
108	Fremont	" "	.037
107	First	" "	.018
Avg.			.028
	CALIFORNIA STREET		
123	Market and Drumm	Yerba Buena Cove	.029
122	Davis St.	" "	.030
121	Front	" "	.030
120	Battery	" "	.025
119	Sansome	" "	.020
Avg.			.027
	WASHINGTON STREET		
143	Embarcadero	Yerba Buena Cove	.058
142	Drumm	" "	.032
141	Davis	" "	.015
140	Front	" "	.010
138	Battery	" "	.015
137	Sansome	" "	.008
	JACKSON STREET		
139	Embarcadero	Yerba Buena Cove	.052
149	Drumm	" "	.031
148	Davis	" "	.009
147	Front	" "	.009
146	Battery	Westshore Yerba	.0015
145	Sansome	Yerba Buena Cove	.003
144	Montgomery	" "	.004
	7th STREET		
83	Mission		.021
81	Howard		.002
75	Folsom	Mission Swamp	.031
69	Harrison	" "	.033
64	Bryant	" "	.009
59	Brannon	Mission Bay	.073
53	Townsend	" "	.011
	FOLSOM STREET		
74	8th		.011
75	7th	Mission Swamp	.031
76	6th	" "	.210
77	5th	" "	.036
78	4th	" "	.014

Maximum rates of settlement are seen to occur in areas of greatest depth of soft materials, as along the Embarcadero traversing the former site of Yerba Buena Cove, and along the lower portions of tributary lateral streets such as Market, California, Washington and Jackson Streets. The maximum rate along the Embarcadero is .058 feet per year and the average .044 feet. Settlement rates decrease on tributary streets as the old shore line of Yerba Buena Cove is approached although those on Market Street, as far up as Bush and Battery Streets, are large, averaging .041 feet on the north side and .028 on the south side. On Folsom and 7th Streets which traverse the historic Mission Swamp, local rates are higher, reaching a maximum of .210 feet per annum at Folsom and 6th Streets.

Buildings

Another activity of the San Francisco Foundations Committee has been the compilation and analysis of settlement records at large buildings. Three such studies have been completed to date: the Pacific Gas and Electric Company Building, Market and Beale Streets, reported upon by Mr. James P. Hawke, A.M., ASCE: the Standard Oil Building, Bush and Sansome Streets, reported upon by Mr. Elmer F. Steigleman, A.M., ASCE; and the Shell Building, Bush and Battery Streets, reported upon by Messrs. Harry A. Williams, A.M., ASCE, and Robert B. Kavinoky, Jun. M., ASCE. The settlement records for these buildings, compiled from the above reports, are shown on Diagram 7, and the building locations on Diagram 10. Settlement within each building area, as of latest date available, is indicated on Diagram 9 by means of settlement contours. Total observed settlement in feet at these buildings has been as follows:

BUILDING	PERIOD	NUMBER POINTS OBSERVED	MAXIMUM	MINIMUM	AVERAGE
PG&E Bldg.	May 1925 to Oct. 1947	9	0.27	0	0.14
Shell Bldg.	Feb. 1922 to Dec. 1950	57	0.59	0.43	0.52 (a)
Standard Oil Bldg.	Feb. 1922 to Dec. 1950	10	0.84	0.51	0.64

(a) Maximum differential settlement between tower columns 1/2 inch for columns 80 ft. apart.

These buildings are in the financial section of San Francisco where land values are the highest. They are underlain by a series of deposits consisting of wind-blown sand, soft bay mud, alluvial yellow sandy clays, and blue marine clays extending to great depth. A geological profile of Market Street, prepared from all available test boring data, is typical of the sequence of subsurface formations in the area (Diagram 8). This profile lies parallel with and one block northwest of the thread of the deep canyon through which Mission Creek drainage formerly discharged, and which was drowned by the flooding of the valley of San Francisco Bay (Diagrams 1 and 10). The soft bay

mud deposits extend from the present bay front up as far as Battery Street. The mud is covered by wind-blown sand and by artificial fill used to raise building lots up to grade in former Yerba Buena Cove. Below the mud is a series of sandy clay beds 50 feet in thickness of both alluvial and marine origin. Below these beds is a deposit of blue marine clay representing ancient estuarial deposits approximately 70 feet in thickness and extending from the bay front to Montgomery Street. The bedrock lies at from 210 to 275 feet below the surface. It is to be noted that the foundations of the PG & E and Shell Buildings extend down to the top of the deeper blue marine clay while that of the Standard Oil Bldg. rests upon the yellow alluvial sands and sandy clays lying above the blue clay.

The three buildings have differing types of foundations. At the PG& E Building the column loads are supported by footings resting upon clusters of timber piles, the latter being driven to refusal at an approximately uniform penetration, averaging -97 feet MSL elevation. Considerable difficulty was encountered in driving piles through local areas (or "kidneys") of hard sandy clay[2], making it necessary to jet 389 of the 1470 piles. The design pile load was 54 kips per pile and the indicated bearing capacity of test piles exceeded 150 kips by the Engineering News formula and 84 kips by the Boston formula. The rate of settlement of the building during the period 1938 to 1944, when street settlement records are available, was .014 feet per year, while that of the adjacent street was .017 feet per year. This indicates that the building load is supported at a level below the soft bay mud, presumably by the frictional resistance of the piles against the 50 feet of sandy alluvial clays (Diagram 8).

The street on the other hand is supported by the upper soft bay mud. The piles distribute the load vertically and apparently the pressure upon the lower compressible blue clay stratum is so diluted that settlement in that stratum caused by the building load is inappreciable. The fact that the rate of street settlement at Beale and Market is the least along the south side of Market Street (Table 4) indicates that the piles may also have developed friction against upper sand layers, thus transferring load from the soft bay mud to the piles, with resultant decrease in rate of street settlement.

In contrast with the PG&E Bldg. is the Shell Building, where belled concrete caissons were used, having 6.5 to 7.5 feet column diameter and 12 to 15 feet bells. Caisson holes were excavated and carried down to an average depth of 82 feet, penetrating the lower blue marine clay stratum by approximately 12 feet. The total thickness of the deeper blue clay at this point is about 80 feet (Diagram 8). The design bearing capacity for the blue clay was taken as 7 tons per sq. ft. Pressures were made approximately equal for all caissons at 6 tons per sq. ft., of which 5.3 was dead load and 0.7 live load. At this site the rate of settlement of the building during the period when street elevations are available, 1930 to 1936 inclusive, was .047 feet per year (Diagram 7). Adjacent street settlement prior to construction was .020 feet per year but during the 7 years following completion of the building it increased to .067 feet per year. This great increase indicates that the frictional resistance developed by the caissons in the alluvial sandy clays above the blue clay is nominal, the load being carried to the belled footings where it is supported by the blue clay. The pressure at caisson footings has apparently induced active consolidation affecting an area not only beneath the building but

2. Report of Subsoil Committee, San Francisco Section, ASCE, Subsidence and the foundation problems in San Francisco, p. 53, 1932.

surrounding it. Prior to construction the local street settlement resulted from consolidation of the upper soft bay mud alone, but with the placing of the building load directly upon the lower blue clay, consolidation in the latter caused added settlement which carried down with it the upper strata, producing an aggregate annual rate of street settlement of .020 + .047 = .067 feet per year which was the observed rate. The effect of settlement at Shell Building may also have extended to the PG&E Bldg. in slight degree, as is suggested by the accelerated settlement rate at that building immediately following completing of the Shell Building (Diagram 7). In recent years the settlement curve for Shell Building has followed a straight line, possibly indicative of having attained to a prolonged stage of secondary consolidation in the underlying blue clay.

The Standard Oil Building presents still another situation. The foundation of this building is a concrete mat stiffened by continuous concrete ribs 7 feet in depth with spread footings at elevation -7.3 feet, designed for a unit loading of 2.4 tons per sq. ft. The bed of soft bay mud on Bush Street does not extend above Battery Street and is not encountered in test borings within this building site. The lower blue clay, however, does underlie the site, although with a thickness of only 50 feet., which is separated into two layers by intrusion of beds of yellow sand and sandy clay. The total thickness of sand and sandy clay lying between the footing elevation and the top of the blue clay is 50 feet (Diagram 8). Following construction the building experienced a settlement averaging .042 feet per annum from 1922 to 1933 (Diagram 7). Since that date it has progressively slowed down following the pattern of a typical consolidation test curve in the transition from primary to secondary consolidation.

The result of transferring the heavy building load to the foundation material at only one horizon is to produce relatively large settlement, as illustrated by the record at both Standard Oil and Shell Buildings (Diagram 7). On the other hand, relatively small settlement has occurred at PG&E Bldg. where the load has been distributed vertically through a 50-foot series of sandy clay alluvial beds. The records at Standard Oil Building, in conjunction with that at the other two buildings, indicate that the method of applying the building load to the foundation may have a greater influence upon settlement than do the consolidation characteristics of the underlying soils.

Prior to construction of Standard Oil Building there was an elongated area of excessive street settlement, beginning at Sansome Street between Bush and Pine Streets and extending to Battery and Front Streets between California and Market Streets. The highest rate of settlement in this entire area was in the block bounded by Battery, Front, California, and Pine Streets. The average annual rate of settlement in this block during the period 1923 to 1928 was 0.05 feet per year[3]. The available record of street settlement at Pine and Battery, furnished by the City Engineer, beginning in 1924 with intermittent observations until 1940, is reproduced on Diagram 7. This graph indicates a steepening in the rate of settlement after 1928. This may have been caused by increased pressure resulting from construction of Shell Building in 1930. The settlement in this area thus appears to reflect consolidation of the lower blue clays as well as the soft bay mud. The underlying cause of the settlement appears to be the consolidation, produced by the general building load in the area, acting upon the tongue of deepmarine blue clay extending up to Montgomery Street and confined within the basin formed by the bedrock

3. Report of Subsoil Committee, San Francisco Section, ASCE, Subsidence and the foundation problems in San Francisco, Plates II and III, 1932.

ravine whose thread follows Bush Street to Sansome and thence to the intersection of Battery and Pine Streets (Diagram 10). This body of highly compressible material has the same limits as the area of active settlement and it exceeds in depth by 25 to 50 feet that of adjacent areas. It thus has greater potentiality for settlement than surrounding areas. The three buildings under discussion lie around the rim of this basin. They have contributed to the local enlargement of the original settlement area and have also caused local increase in street settlement rate. The available information indicates that soil pressure resulting from the general building load is predominant in causing street settlement.

An item of interest shown on Diagram 7 is the temporary heaving of PG& E Building produced by driving of piles at the Annex Building in 1947. The fact that resumption of settlement in PG& E Building had not yet occurred at several observational points at the time of last readings raises question as to the possibility that overloading of the underlying blue clay has occurred, with resultant plastic flow. The abnormally prolonged period of relatively rapid uniform settlement in the secondary stage of consolidation in the blue marine clay at Shell Building raises the same question. This is a situation which will bear watching in the future as more and more tall buildings are erected upon the area underlain by the deeper blue clay. Although the vertical distribution of loading throughout the upper yellow sandy clays, as attained at the PG& E and Matson Buildings, may so dilute the pressure upon the blue clay that consolidation of the latter does not occur with distributed load, yet with a concentration of building loads and possible further utilization of the blue clay in direct bearing, as at Shell Building, the day may come when this problem will arise. A possibility, which has been frequently discussed among foundation engineers, is that the general settlement which has been taking place in the lower Market Street area is partially caused by plastic flow of mud toward the bay. Similar discussion with regard to the deeper blue clay may occur at some future date.

The conclusions to be drawn from the experience at these three buildings will doubtless vary, depending upon the individual point of view. One which occurs to the writer is the great advantage which results from the use of friction piles to support a building at a site deeply underlain by highly compressible materials blanketed by competent sand and sandy clay strata. The essence of this advantage appears to lie in the greater spread of the pressure bulb by transfer of the load through a wide vertical range, thus reducing the unit pressure upon the deeper compressible material. With the development of modern power-driven auger equipment capable of excavating large diameter holes and of belling in cohesive materials it would appear that this advantage is not confined to driven pile foundations. Bored caissons in which concrete is poured against the natural undisturbed walls of the excavation should develop friction equal or greater than wooden piles and without the disadvantage of pile driving in causing injury to adjacent structures by vibration or by consolidation or heaving of the adjacent soils. Experience has shown that bore holes in caving or running sand can be cased as boring proceeds and that the casing can be pulled progressively as concrete is poured. This method of foundation construction should greatly simplify or eliminate the underpinning problems encountered in open caisson excavations where there are adjacent buildings.

It is hoped that this paper will not alone elicit discussion but will also bring forth contributions of basic data regarding soil characteristics and records of settlement in the San Francisco area. The work of the Soils and

Foundations Committee, San Francisco Section, ASCE, and other agencies has been but briefly summarized herein. It is the plan of the Committee to publish these data in detail at some future date. The Subsidence Report of the local Subsoil Committee, issued in 1932, is still in great demand by engineers throughout the world. The value of the proposed report to all members of the profession can be enhanced to the degree that additional information is made available.

LIST OF DIAGRAMS


GOLDEN GATE
PRESIDIO
PACIFIC OCEAN
SAN FRANCISCO BAY
GOLDEN GATE
Eureka Valley
Noe Valley
Lake Merced
City and County
SAN BRUNO MOUNTAINS
LEGEND
Natural Historic Drainage Divides
Ancient Geological Drainage Divide
Former Historic Stream Channels
Ancient Geological Stream Channels
Shore Line of 1850
Important Streets
Location of Test Boring with Soil Test Data
OUTLINE MAP OF SAN FRANCISCO
SHOWING
DRAINAGE AREAS, STREAM CHANNELS
AND SHORE LINE OF 1850.

Diagram 1

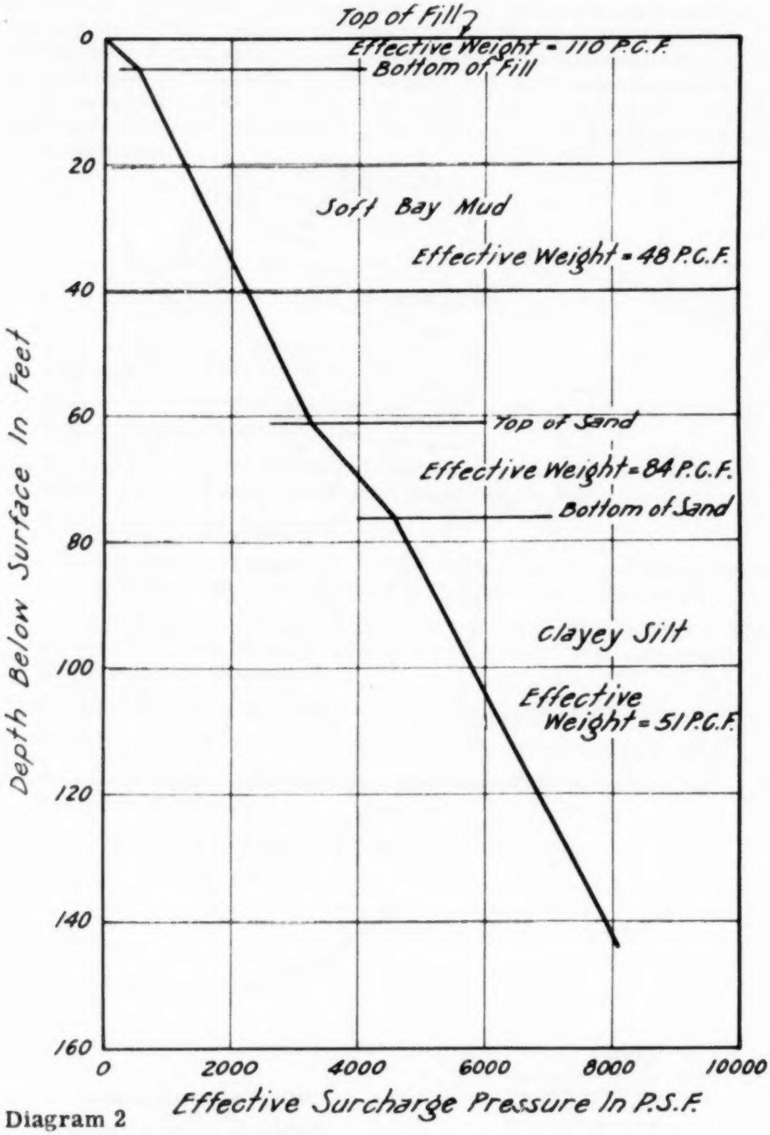
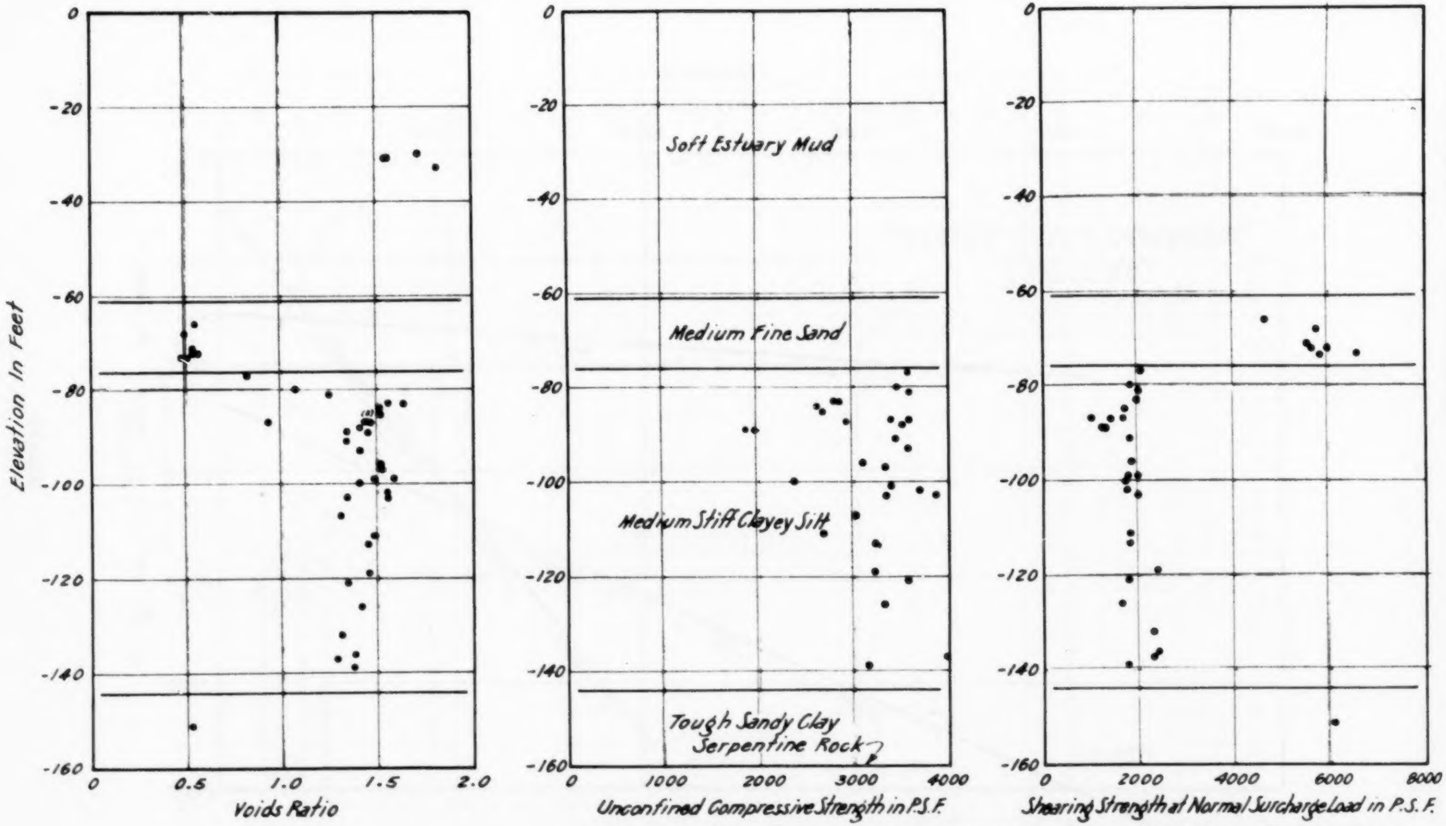


Diagram 2

TYPICAL EFFECTIVE NATURAL SURCHARGE LOAD
ON SUB-SURFACE MATERIALS
SAN FRANCISCO WATERFRONT



TYPICAL VOID RATIOS, UNCONFINED COMPRESSIVE STRENGTH AND SHEARING STRENGTH FOR SUB-SURFACE MATERIALS SAN FRANCISCO WATERFRONT

Diagram 3

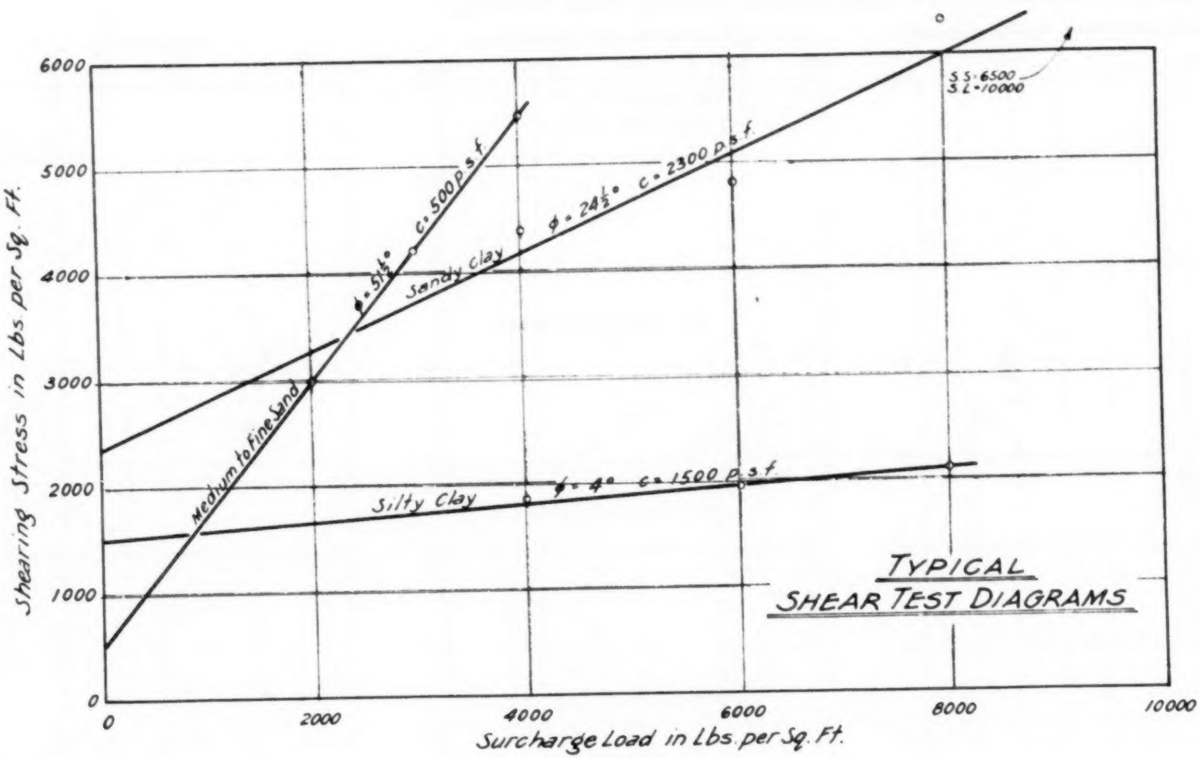
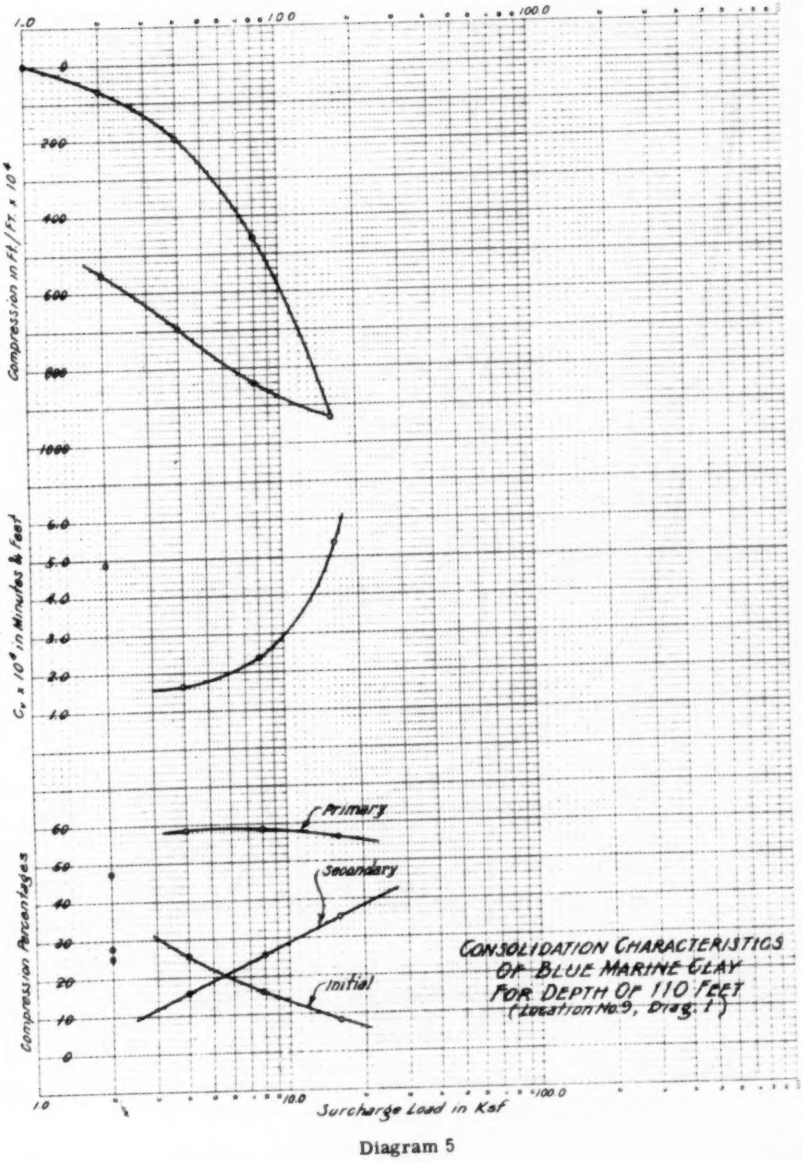
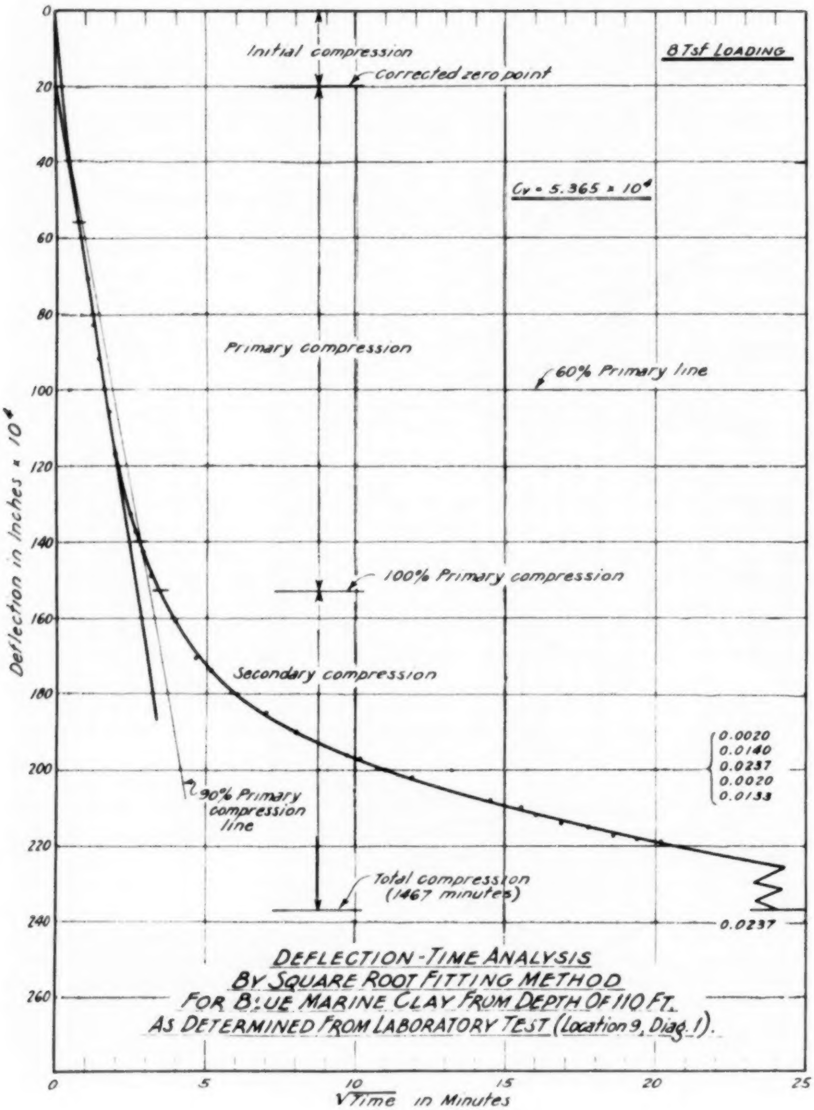

TYPICAL
SHEAR TEST DIAGRAMS
Shearing Stress in Lbs. per Sq. Ft.
Surcharge Load in Lbs. per Sq. Ft.
0
1000
2000
3000
4000
5000
6000
0
2000
4000
6000
8000
10000
Medium to Fine Sand
φ = 51½° c = 500 p.s.f.
Sandy Clay
φ = 24½° c = 2300 p.s.f.
Silty Clay
φ = 4° c = 1500 p.s.f.
S.S. 6500
S.L. 10000

Diagram 4



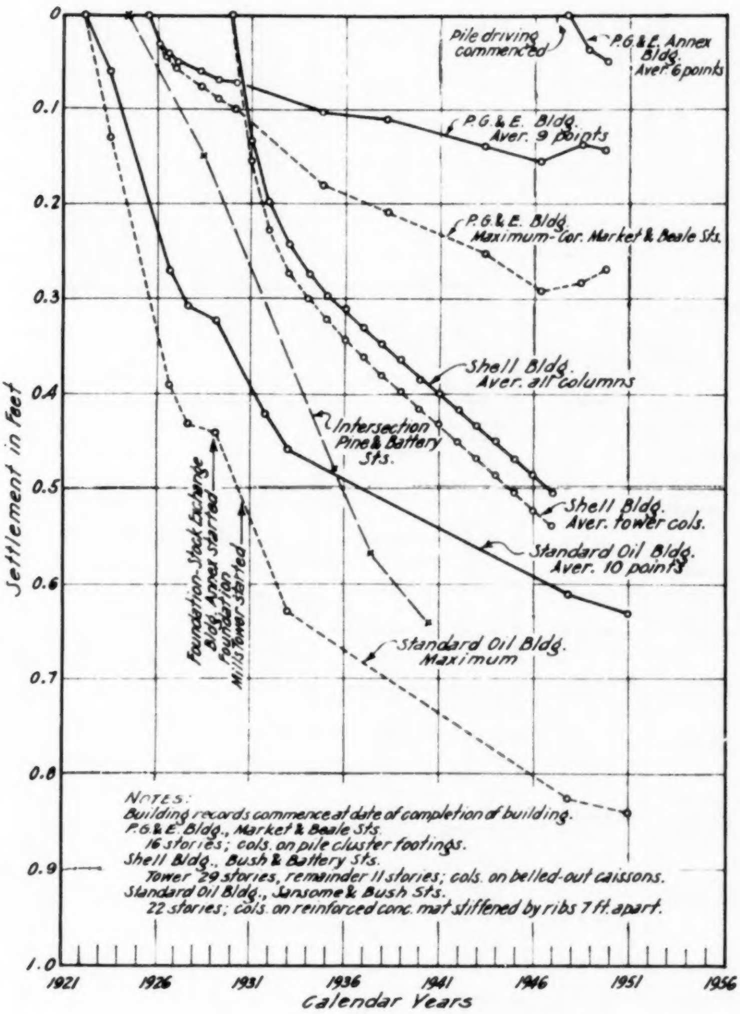
Compression in Ft/Ft. x 10⁴
Cᵥ x 10⁴ in Minutes & Feet
Compression Percentages
Primary
Secondary
Initial
CONSOLIDATION CHARACTERISTICS
OF BLUE MARINE CLAY
FOR DEPTH OF 110 FEET
(Location No.9, Diag. 1)
Surcharge Load in Ksf

Diagram 5



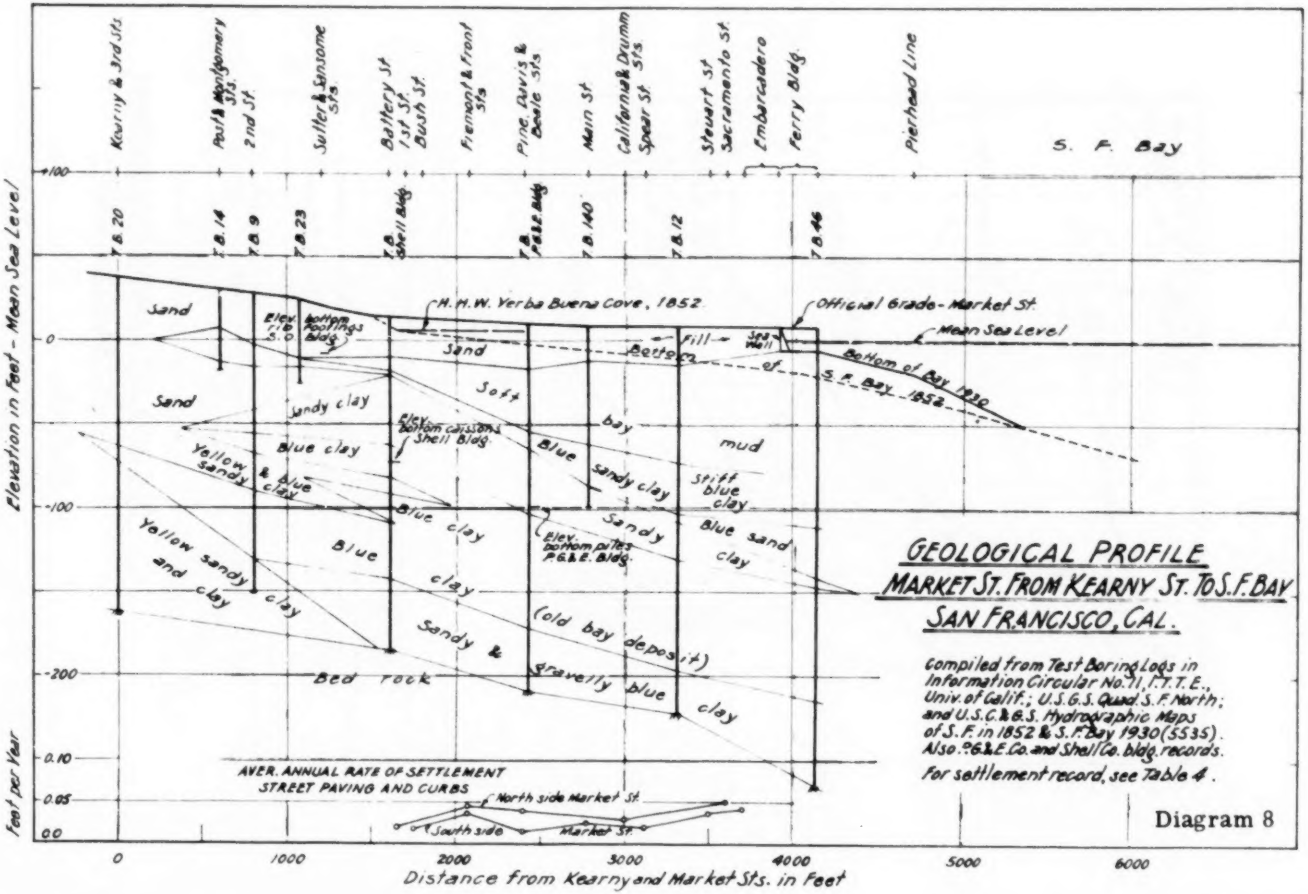
Initial compression
8 Tsf LOADING
Corrected zero point
Cv = 5.365 x 10⁴
Primary compression
60% Primary line
Deflection in Inches x 10⁴
100% Primary compression
Secondary compression
0.0020
0.0140
0.0237
0.0020
0.0133
90% Primary compression line
Total compression (1467 minutes)
0.0237
DEFLECTION-TIME ANALYSIS
BY SQUARE ROOT FITTING METHOD
FOR BLUE MARINE CLAY FROM DEPTH OF 110 FT.
AS DETERMINED FROM LABORATORY TEST (Location 9, Diag. 1).
√Time in Minutes

Diagram 6



BUILDING SETTLEMENT RECORD CURVES
SAN FRANCISCO, CALIF.

Diagram 7

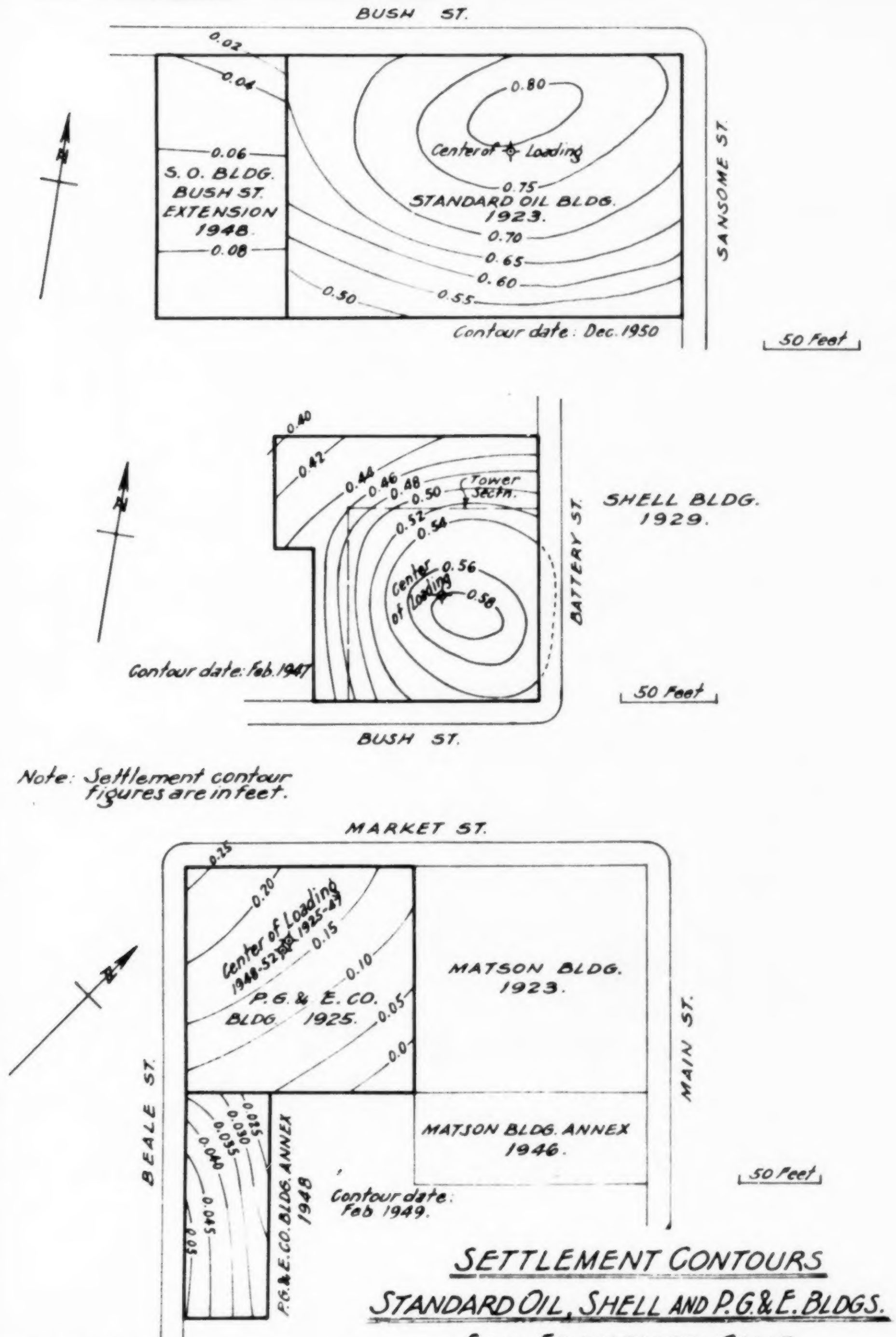


GEOLOGICAL PROFILE
MARKET ST. FROM KEARNY ST. TO S.F. BAY
SAN FRANCISCO, CAL.

Compiled from Test Boring Logs in Information Circular No. 11, I.T.T.E., Univ. of Calif.; U.S.G.S. Quad. S.F. North; and U.S.C.&G.S. Hydrographic Maps of S.F. in 1852 & S.F. Bay 1930 (5535). Also P.G.&E. Co. and Shell Co. bldg. records.

For settlement record, see Table 4.

Diagram 8



SETTLEMENT CONTOURS
STANDARD OIL, SHELL AND P.G.&E. BLDGS.
SAN FRANCISCO, CALIF.

Diagram 9


MAP OF FINANCIAL DISTRICT
SAN FRANCISCO, CALIF.
EMBARCADERO
STEUART ST
SPEAR ST
MAIN ST
BEALE ST
FREMONT ST
FIRST ST
SECOND ST
NEW MONTGOMERY ST
MISSION
THIRD ST
DRUMM ST
DAVIS ST
FRONT ST
BATTERY ST
SANSOME
MONTGOMERY
KEARNY ST
GEARY ST
MARKET
POST ST
SUTTER
BUSH
PINE
CALIFORNIA
SACRAMENTO
COMMERCIAL ST
CLAY ST
LEGEND

Diagram 10